Harmful Algae 61 (2017) 31–45

Contents lists available at ScienceDirect

Harmful Algae

journal homepage: www.elsevier.com/locate/hal

Review

A review of microcystin detections in Estuarine and Marine waters: Environmental implications and human health risk

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ARTICLE INFO

Article history:
Received 27 June 2016
Received in revised form 29 October 2016
Accepted 11 November 2016
Available online 29 November 2016

Keywords:
CyanoHAB
Microcystin
Salinity tolerance
Estuarine
Coastal
Freshwater transfer
Human health

ABSTRACT

Toxin production by harmful cyanobacteria blooms (CyanoHABs) constitutes a major, worldwide environmental threat to freshwater aquatic resources that is expected to expand in scale and intensity with global climate change. Extensive literature exists on the most frequently encountered cyanotoxin, microcystin, in freshwater environments. Yet, the expansion of microcystin producing CyanoHABs and the transport of contaminated inland waters to estuarine and coastal marine waters has only recently received attention. This paper synthesizes information on the salinity tolerance of microcystin producing cyanobacteria and summarizes available case reports on microcystin presence in estuarine and coastal waters. We highlight a potential food-borne exposure route to humans by reviewing the growing body of evidence that shows microcystins can accumulate in coastal seafood. These cases reinforce the importance of freshwater nutrient reduction and the need for freshwater management efforts to look beyond lacustrine and riverine systems. Events reviewed here likely only represent a small proportion of cases where microcystins affect estuarine and coastal waters. We strongly suggest increased monitoring and research efforts to understand, react to, and prevent ecological and health problems associated with the growing problem of toxic CyanoHABs in coastal environments.

Contents

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http://dx.doi.org/10.1016/j.hal.2016.11.006
1568-9883/

1. Introduction

Harmful cyanobacteria blooms (CyanoHABs) are comprised of naturally occurring photosynthetic prokaryotes found in a wide variety of aquatic environments and capable of producing toxic secondary metabolites (cyanotoxins). CyanoHABs can thrive under a wide range of environmental conditions and are especially prolific and competitive under high nutrient conditions often associated with eutrophic waters. Although nutrient loading is a strong risk factor for bloom promotion, no single environmental or anthropogenic factor has been identified to cause bloom formation. Nonetheless, large scale ecological disturbances associated with urbanization, rising agricultural activities, and introduction of invasive species (Bykova et al., 2006), combined with climate change have escalated the intensity, frequency and geographic distribution of CyanoHABs (Carey et al., 2012; Paerl and Huisman, 2009; Paerl and Paul, 2012; Visser et al., 2016). For example, in the United States, CyanoHABs previously affected only a few regions, but major blooms now impact lakes, rivers, wetlands, estuaries and nearshore marine waters across the country (Glibert et al., 2005). Proliferation and dominance of CyanoHABs have been observed worldwide, with approximately 75% of cyanobacteria blooms known to be toxic (Chorus et al., 2000). The myriad of water quality, fisheries, recreational, animal and human health problems associated with cyanotoxins are expected to rise as CyanoHABs increase in severity (Falconer and Humpage, 2005).

Hepatotoxic microcystins (MCs) are the most common cyanotoxins, with over 100 known variants (Vesterkvist et al., 2012). MCs are small, monocyclic peptides composed of seven amino acids connected via peptide bonds with the general structure cyclo(D)-Ala-X-(D)-*erythro*-β-methyl-*iso*-Asp-Y-Adda-(D)-*iso*-Glu-*N*-methyldehydro-Ala (Fig. 1); X and Y represent positions occupied by the variable L-amino acids (Codd et al., 2005; Welker and von Döhren, 2006). The unusual Adda amino acid, unique to MCs, is often associated with toxicity of the molecule (Dawson, 1998).

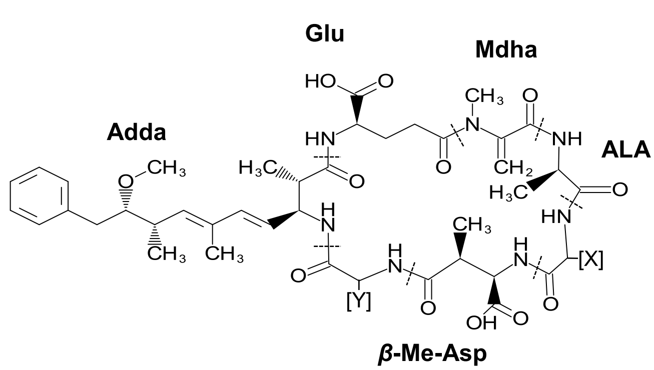

Fig. 1. Structure of the peptide hepatotoxin, microcystin.

MCs are potent inhibitors of the serine threonine protein phosphatases (PPs) PP1 and PP2A (MacKintosh et al., 1990). Inhibition of protein phosphatase can lead to accumulation of phosphorylated proteins in the liver causing cell necrosis, massive hemorrhage and death (Bhattacharya et al., 1997; Merel et al., 2013). Acute or chronic MC exposures may cause permanent liver damage (Li et al., 2011), and promote tumors (Nishiwaki-Matsushima et al., 1992; Grosse et al., 2006; Fujiki and Suganuma, 2011). Due to the toxicological effects from MCs, exposure to the toxins presents a health hazard and numerous MC poisonings have been documented in pets, livestock, wildlife, and humans (Mez et al., 1997; Azevedo et al., 2002; Merel et al., 2013; Backer et al., 2013; Hilborn et al., 2014).

MCs are commonly produced by the genera, *Anabaena* (*Dolichospermum*), *Aphanizomenon*, *Microcystis*, *Planktothrix* and more rarely by *Anabaenopsis*, *Aphanocapsa*, *Cylindrospermopsis*, *Fischerella*, *Gleotrichia*, *Gomphosphaeria*, *Hapalosiphon*, *Nodularia*, *Nostoc*, *Oscillatoria*, *Phormidium*, *Pseudanabaena*, *Synechococcus* (Sivonen and Jones, 1999; Chorus et al., 2000; Mohamed and Carmichael, 2000; Paerl and Otten, 2013; EPA, 2015). Cyanobacteria of the genus *Microcystis* are among the most common producers of freshwater blooms on every continent except Antarctica (Carmichael, 1992) and some level of toxins are frequently associated with these blooms (Carmichael, 1995). A recent review found documentation confirming *Microcystis* blooms from 108 countries and territories; MCs were found in 79 of these locations (Harke et al., 2016).

Reports of CyanoHABs in brackish waters are on the rise (Paerl and Paul, 2012), yet MCs remain under-investigated in estuarine and marine waters. Since coastal watersheds support more than half of the world's population (NOAA, 2012; Ache et al., 2013), it is critical to better understand MC dynamics in saline environments. Other than the review by Vareli et al. (2013) emphasizing MC production by marine phytoplankton, there is little summary literature on MC-producing CyanoHABs in marine and estuarine systems or on delivery of MC-contaminated freshwaters polluting nearshore environments. Because of their high potential for human health impacts, a review of MCs in brackish and saline environments is particularly appropriate and timely. This review summarizes: 1) known effects of salinity on MC producing cyanobacteria, 2) MC-producing CyanoHABs in estuarine and nearshore coastal environments, 3) case studies documenting transfer of MCs from freshwater to coastal ecosystems and 4) MC accumulation in estuarine and marine seafood, emphasizing organisms consumed by humans.

2. Salt tolerance of CyanoHABs

A wide range of environmental variables including salinity, temperature, nutrient and light availability, residence time, turbulent mixing and grazing, can influence CyanoHAB formation